Demonstration of the SSFATE Numerical Modeling System

PURPOSE: This technical note presents a demonstration of the SSFATE (Suspended Sediment FATE) model. SSFATE fulfills a need for a suspended sediment plume modeling tool that enables the user to quickly and cost-effectively simulate multiple dredging project scenarios. The flexibility inherent in SSFATE, coupled with an ability to simulate most commonly used dredge plants (e.g., bucket, hydraulic pipeline, or hopper) and dredging practices (e.g., barge or hopper overflow, multiple plants operating simultaneously), is intended to assist in the negotiation process of reasonable, objectively defined environmental windows. This note exemplifies an application of SSFATE for an actual dredging project involving consideration of environmental windows.

BACKGROUND: The U.S. Army Engineer District, New England (NED), prepared a Draft Environmental Impact Statement (DEIS) for the proposed Providence River and Harbor Maintenance Dredging Project (U.S. Army Engineer District (USAED), New England, 1998). Comments received on the DEIS recommended that dredging be allowed only at certain times (environmental windows) to minimize potential impact to marine resources. Because the proposed project is estimated to last 18 months with 24-hr/day dredging, constraints on periods when dredging is allowed would extend the schedule even longer. The NED is conducting additional studies to determine whether the use of environmental windows is justified both environmentally and economically. Modeling of the plumes generated from the dredging process to determine the extent and duration of such plumes is one component of these additional studies. This component provided an ideal opportunity for an initial demonstration of the SSFATE model.

Under contract with the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, Applied Science Associates, Inc. (ASA) was responsible for the development of the SSFATE model. Because of this development and ASA's experience in modeling various processes in Narragansett Bay and the Providence River, ASA was retained by NED to conduct a modeling study to aid in addressing environmental issues identified during interagency coordination at the DEIS. The modeling study involved an application of SSFATE to estimate total suspended solids (TSS) concentrations and the spatial extent of suspended sediment plumes generated by the dredging operation, as well as an application of ASA's WQMAP modeling system (ASA 1997) to compute the concentration of copper in the water column (Swanson, Isaji, and Ward 2000). A series of sites were selected along the channel for generation of suspended sediment plumes. Different bucket types and barge overflow protocols were chosen to simulate the range of expected actual conditions. This technical note describes only the SSFATE application component of the modeling study.

DESCRIPTION OF THE STUDY AREA: The Providence River and upper Narragansett Bay (Figure 1) are connected to Rhode Island Sound through the east and west passages of Narragansett Bay. The Providence River in the Harbor area down to the upper end of Fuller Rock Reach is approximately 500-m- (1,700-ft-) wide. It continues to widen to its mouth at Conimicut Point located

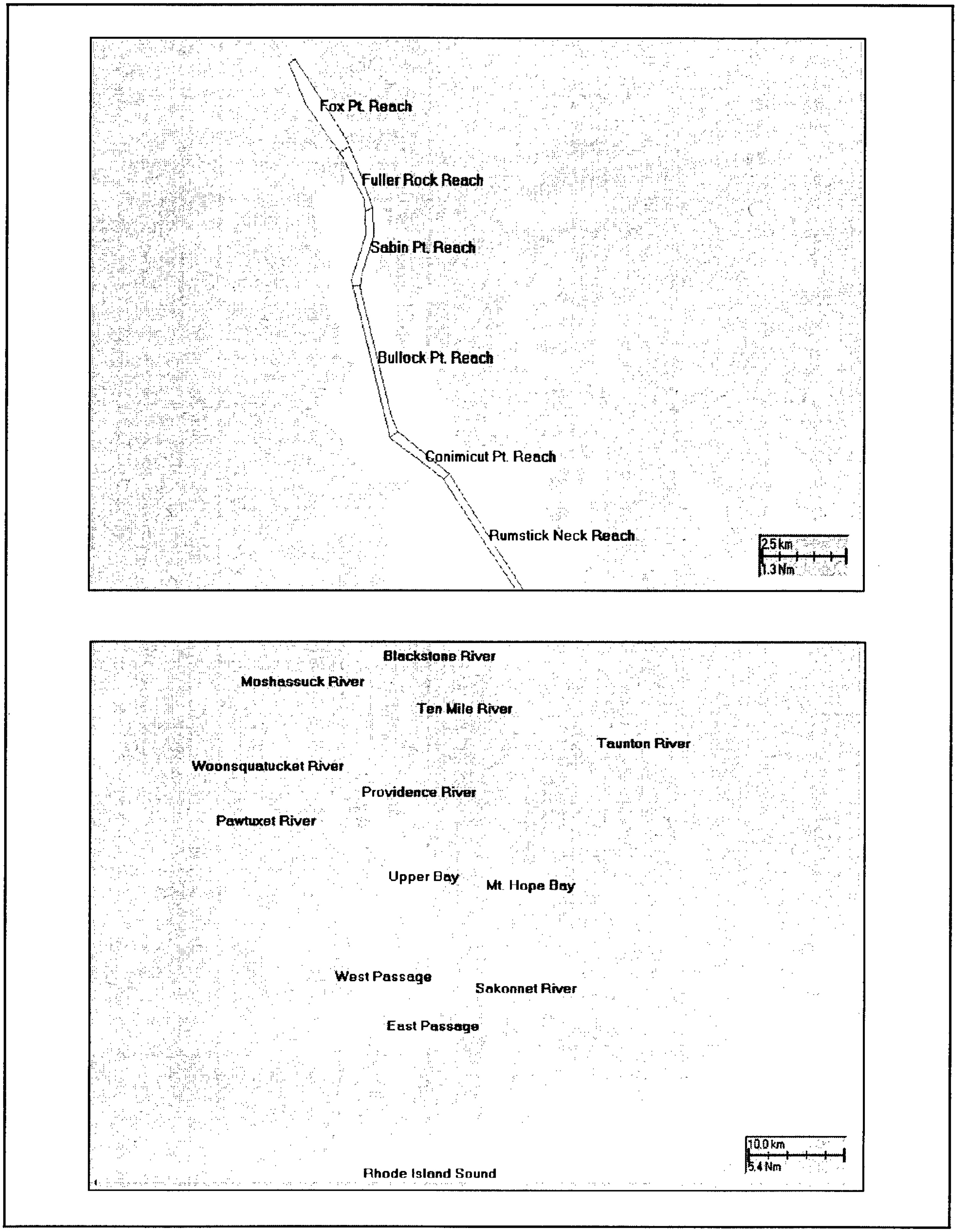

Figure 1. Location of the Providence and Upper Narrangansett Bay (lower panel) and harbor and channel areas to be dredged (upper panel)

11.6 km south of Fox Point Reach. The river then merges with upper Narragansett Bay, which eventually splits into its east and west passages to Rhode Island Sound.

The navigation channel runs from upper Narragansett Bay through the Fox Point Reach. The channel design depth is 12.2 m (40 ft) at mlw. It is typically 200-m- (650-ft-) wide below Fox Point Reach and is flanked by wide shallow areas typically 1-2 m (3-7 ft) deep. In Fox Points Reach, the deep dredged area widens to both banks of the river, 500 m (1,600 ft), to accommodate shipping traffic.

Hydrodynamic conditions at a dredging site play a crucial role in the modeling of suspended sediment plumes. The tide range in the upper bay and Providence River averages 1.40 m (4.6 ft) in the Providence Harbor, with the spring range being 1.71 m (5.6 ft). The tide is primarily a standing wave with maximum tide-induced velocities approximately 90° out of phase with tide height. Circulation in the Providence River and upper Narragansett Bay is dominated by the tides. Based on an analysis of current meter data obtained at three locations in the river, Turner (1984) concluded that approximately 70-80 percent of current variance occurs at tidal frequencies. More than 50 percent of the variance is present at the semidiurnal M_2 constituent (12.42 hr) period. Typical tidal velocities in the river range from 10 to 25 cm/sec (0.32 to 0.82 ft/sec).

The tidal prism of the Providence River is approximately 32×10^6 m^3 (1.1×10^9 ft^3). Converted to an equivalent flow of 1370 m^3/sec (48,500 ft^3/sec), it far exceeds the mean freshwater flow into the system of 43.2 m^3/sec (1,526 ft^3/sec) (Ries 1990). This results in relatively small density-induced flows compared to the tides, although two-layered estuarine circulation has been observed in the Providence River (Turner 1984). This condition is most pronounced under stratified conditions and when there is a relatively strong density gradient up the estuary as a result of low freshwater inflow.

DESCRIPTION OF SSFATE: SSFATE (**S**uspended **S**ediment **FATE**) computes suspended sediment distributions resulting from dredging operations. SSFATE is a versatile computer modeling system containing the following features:

- Ambient currents can either be imported from a numerical hydrodynamic model or drawn graphically using interpolation of limited field data.
- A particle-based computational model computes the transport, dispersion, and settling of suspended dredged material released to the water column.
- Sediment source strength and vertical distribution from cutterhead, hopper, or clamshell type dredges are either computed internally or prescribed as input data.
- The fate of multiple sediment types or fractions can be simulated simultaneously.
- Model output consists of concentration contours in both horizontal and vertical planes, time series plots of suspended sediment concentrations, and the spatial distribution of sediment deposited on the sea floor.
- Sediment particle movement and concentration evolution can be animated over Geographic Information System (GIS) layers depicting sensitive environmental resources and areas.

Depending on the resolution of the numerical grid employed, SSFATE can make predictions close to dredging operations. However, the processes modeled are far field processes in which the mean

transport and turbulence associated with ambient currents dominate. As noted, the transport and dispersion of suspended material from a sediment source are computed using a particle-based model. Particle advection is based on the simple relationship that a particle moves linearly with a local velocity, obtained from the hydrodynamic input, for a specified model time step. Particle diffusion is assumed to follow a simple random walk process. A diffusion distance defined as the square root of the product of an input diffusion coefficient and the time-step is decomposed into x and y displacements via a random direction function. The z diffusion distance is scaled by a random positive or negative direction.

The particle model allows the user to predict the transport and fate of classes of settling particles, e.g., sands, silts, and clays. The fate of multicomponent mixtures of suspended sediments is predicted by linear superposition. The particle-based approach is extremely robust and independent of the grid system. Thus, the method is not subject to artificial diffusion near sharp concentration gradients, and is easily interfaced with all types of sediment sources.

In addition to transport and dispersion, sediment particles also settle at some rate from the water column. Settling of mixtures of particles, some of which may be cohesive in nature, is a complicated process with the different size classes interacting, i.e., the settling of one particle type is not independent of the other types. In SSFATE, particle settling is handled in the following manner. At the end of each time-step, the concentration of each sediment class, as well as the total concentration, is computed on a concentration numerical grid. The size of all grid cells is the same, with the total number of cells increasing as the suspended sediment plume moves away from the dredging source. The settling velocity of each particle size class is computed along with a deposition probability based on shear stress. Finally, the deposition of sediment from each size class from each bottom cell during the current time-step is computed and the calculation cycle begins anew. Additional details concerning SSFATE can be found in Johnson et al. (2000).

APPLICATION OF SSFATE TO THE PROVIDENCE RIVER AND HARBOR DREDGING PROJECT: As noted, SSFATE allows for either importing flow fields computed from a numerical hydrodynamic model or "painting" flow fields from limited field data. ASA's WQMAP three-dimensional (3-D) hydrodynamic model (ASA 1997) was employed to generate flow fields to advect the sediment particles in SSFATE. Figure 2 shows the boundary-fitted computational grid of the area modeled. The horizontal grid size is approximately 100 m (300 ft) in the areas surrounding the dredging sites. The grid has 11 layers that allow simulation of the vertical structure of currents as well. The bathymetry used in the model was taken from digitized National Oceanic and Atmospheric Administration (NOAA) bathymetry.

The hydrodynamic model uses river flow at its northern open boundaries, tidal elevation at its southern open boundaries and the density difference between the fresh river and the saline southern boundary as forcing conditions. For these runs, a constant flow of 24.4 m^3/sec (862 cfs) in the Blackstone River (Figure 1) was prescribed (Ries 1990), and a mean tide range of 1.15 m (3.8 ft) (NOAA 1994) was used to drive the open boundary . The M_2 period (12.42 hr) was used so that a repeating tide could be used in the sediment transport calculation. The open boundary salinity was 32 ppt (Kremer and Nixon 1978). The 3-D hydrodynamic model was calibrated in several recent studies involving dredging activities in Narragansett Bay, e.g., Swanson and Mendelsohn (1998) and Swanson and Ward (1999).

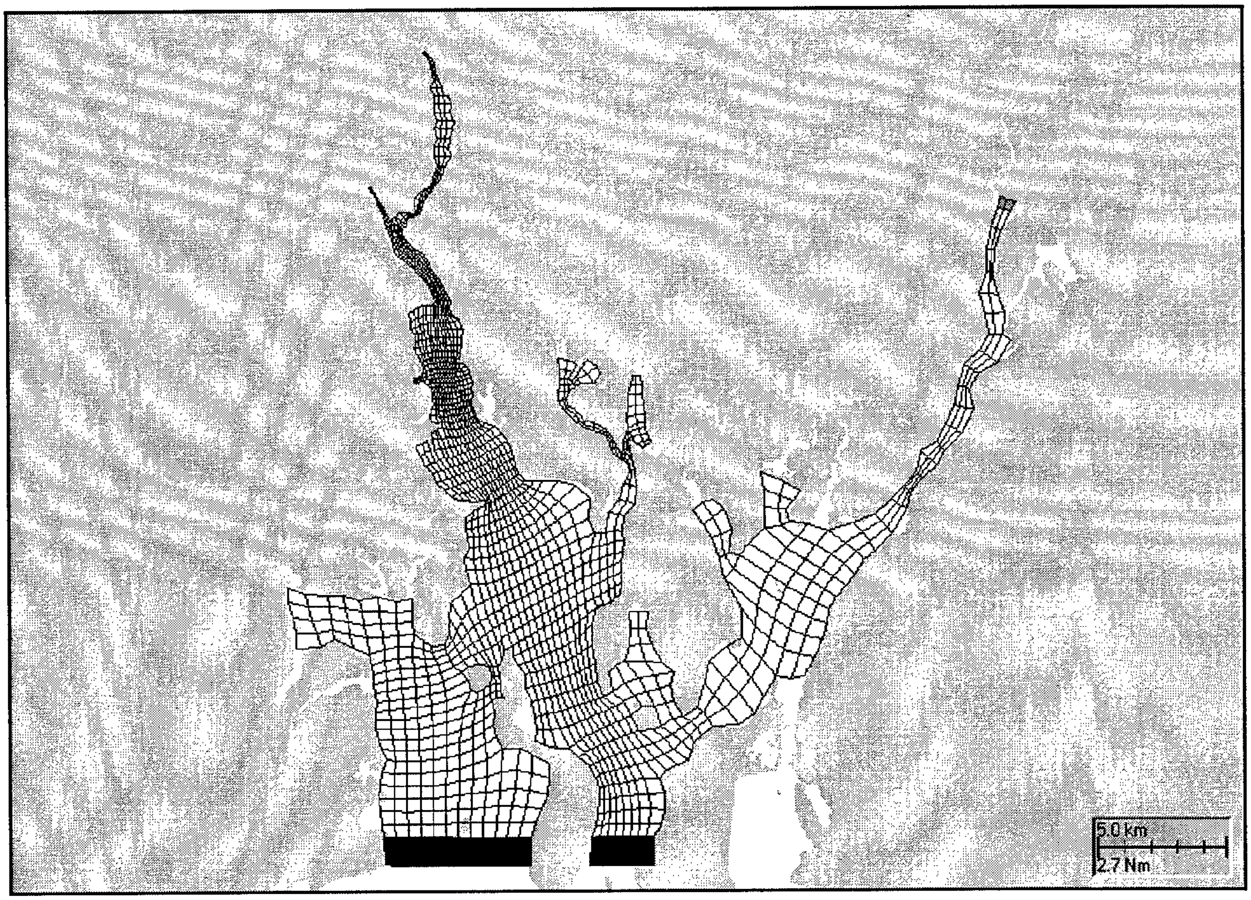

Figure 2. Model computational grid for the Providence River and Upper Narragansett Bay

Using the flow fields provided by the 3-D hydrodynamic model, SSFATE was applied to simulate the fate of dredged material released during dredging operations. The model uses a fine grid (20 m (61 ft) square) that overlies the boundary-fitted hydrodynamic grid shown in Figure 2. This square grid was used to provide finer resolution for the transport calculation while retaining the highly efficient algorithms in SSFATE that advect Lagrangian particles through a square grid. Particle movement is based on an advective velocity calculated from interpolated hydrodynamic model results plus a diffusive velocity that vectorially adds a random component based on a typical estuarine dispersion. A Chezy formulation is used to estimate the diffusion as a function of Manning friction factor, local depth and local velocity (Rouse 1949).

Accurate specification of the sediment loads is crucial when applying SSFATE. For this application, the dredged material loads were assumed to consist of continuous sources of material as opposed to a series of individual events. This approximation was made since the bucket is drawn through the water column with a new load of material approximately every 90 sec. Since the maximum ambient velocity is 10-25 cm/sec (0.33-0.82 ft/sec), the maximum travel distance for a single plume to move away from the dredge is only 9 to 22.5 m (30 to 74 ft). At this distance from the dredge, there is not sufficient resolution to differentiate between consecutive bucket cycles. Thus, a continuous load was used.

Table 1
Size Fraction Distribution of Dredged Material

Material	Percent Composition
Clay	5.6
Fine Silt	5.8
Medium Silt	5.8
Fine Sand	2.8
Fluid	80.0

The sediment fraction distribution of the dredged material is shown in Table 1, and is based on measurements made in the Providence River (USAED, New England, 1998). This distribution contains equal fractions by weight of clay, fine silt and medium silt, with an additional one-half fraction of fine sand.

The specification of the sediment source strength for input to the model is based on an estimated production rate of 7,700 yd^3/day (0.068 m^3/sec). Assuming a solid fraction of 0.2 (20 percent solids) by weight and a sediment density of 2,600 kg/m^3, the mean rate of sediment dredged is 35.4 kg/sec. The source strength is then defined as the percent of this amount that is released to the environment during the dredging operation. The assumed release rates correspond to different bucket types and operational protocols. These rates are1.5 percent for an environmental bucket that seals the bucket load, 2 percent for a conventional bucket, and 4 percent for a conventional bucket with allowance for barge overflow during loading operations (USAED, New England, 1998). The actual model loading rate or source strength for TSS is shown in Table 2.

Table 2
Model Source Strengths of TSS

Release Rate, percent	TSS Loading Rate, kg/sec
1.5	0.53
2.0	0.71
4.0	1.42

Table 3
Vertical Distribution of Material Released into the Water Column during Dredging Operations

Percent of Local Depth	Percent of Material Released
80 – 100 (surface)	5
60 – 80	10
40 – 60	15
20 – 40	30
0 – 20 (bottom)	40

Table 3 shows the percent of material released as a percent of local depth. The load is distributed over the water column with decreasing release amounts from bottom to surface to better simulate release distributions (USAED, New England, 1998).

The assumed locations of the dredging-generated sediment plumes in various channel reaches are shown in Figure 3. The northernmost reach, Fox Point, has two sites in its northern (FPRN) and central (FPRC) areas. The next reach to the south, Fuller Rock, has one site situated at its midpoint (FRRC). The Bullock Point Reach has a site located at its southern end (BPRS) and the Rumstick Neck Reach has a site at its midpoint (RNRC). The FPRC, BPRS and RNRC sites were each evaluated individually for the three release rates. Three additional scenarios that combined FPRN and FPRC; FPRC and FRRC; and FPRN, FPRC and FRRC were also simulated with a 2 percent release rate.

MODEL RESULTS: The modeling results are presented below in two forms: (a) color contours of concentrations in plan and vertical section views that show the maximum horizontal and vertical extent of the resulting sediment plumes; and (b) time-series plots of concentrations at the release site and at specified distances of 150 m (500 ft) and 300 m (1,000 ft) up and down the channel from the release point. These locations correspond to the monitoring requirements for the Boston Harbor Navigation Improvement Project (USAED, New England, 1998). The concentrations presented are excess concentrations since no ambient levels are included. The range of historically observed

ambient TSS concentrations typically vary from 1.63 to 14.8 mg/L (USAED, New England, 1998). These can be added to the model predicted concentrations to obtain total concentrations.

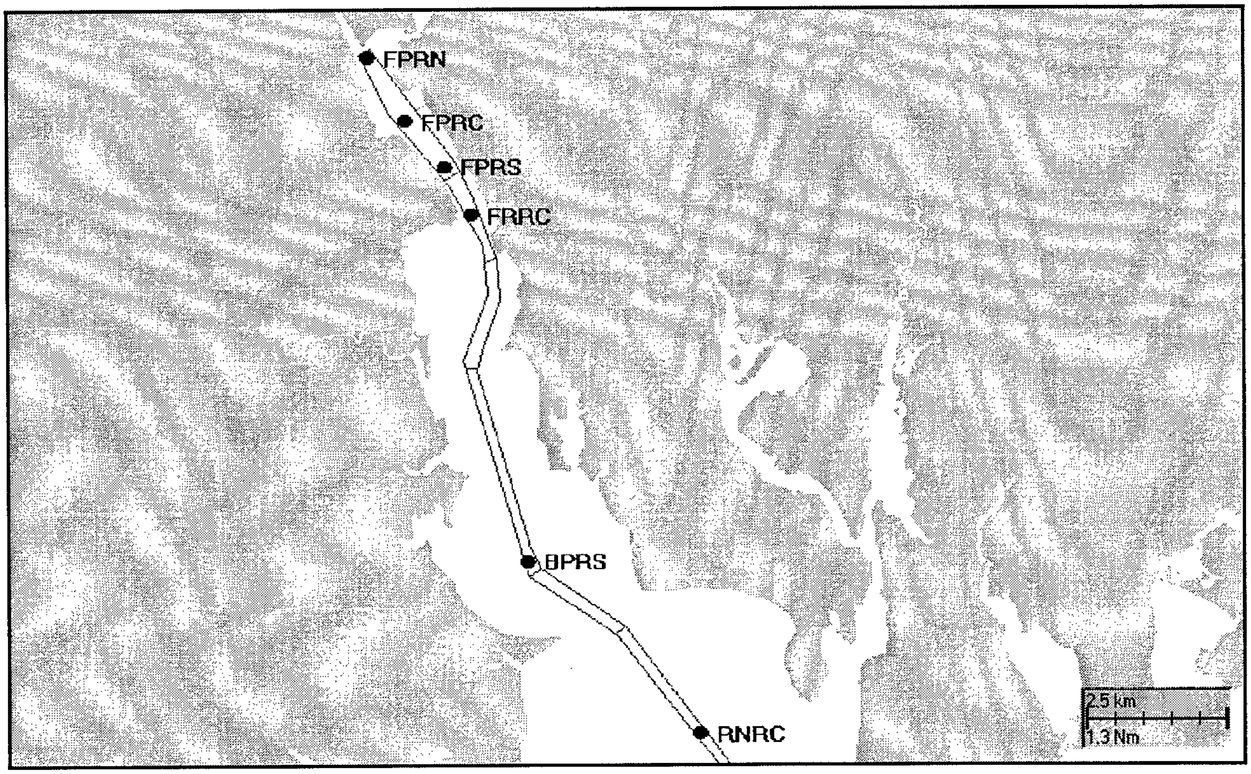

Figure 3. Location of simulated dredging sites in the Providence River and Upper Narragansett Bay from north to south: Fox Point Reach North (FPRN), Fox Point Reach Central (FPRC), Bullock Point Reach South (BPRS), and Rumstick Neck Reach Central (RMRC)

The choice of the TSS concentration levels selected for the presentation of model results corresponds to the ranges presented by Newcombe and Jenson (1996) in a description of their fisheries impacts model. They analyzed a series of studies of fish response to suspended sediment and developed a set of empirical equations that relate biological response to duration of exposure and TSS concentration.

The plan view portion of Figure 4 shows the near surface (0-2 m [0-6 ft]) extent of the sediment plume for the Fox Point Reach Central (FPRC) dredging site with a release rate of 1.5percent, whereas, the cross-section view presents the TSS concentration over the entire water column. The lower panel shows the down channel extent of the plume reached during low slack water while the upper panel shows the up channel extent reached during high slack water. At low slack water, the plume (at a concentration greater than 20 mg/L) extends approximately 1,000 m (3,300 ft) down channel of the dredging site. There is some residual material up channel of the site that was generated during the previous flood tide. At high slack water, the plume extends approximately 780 m (2,550 ft) up channel, with a small amount of material remaining in the water column down channel of the site. The tidal circulation moves the plume up and down the channel away from the release site. Thus, any location away from the immediate dredging site experiences elevated concentrations for only a portion of the tidal cycle.

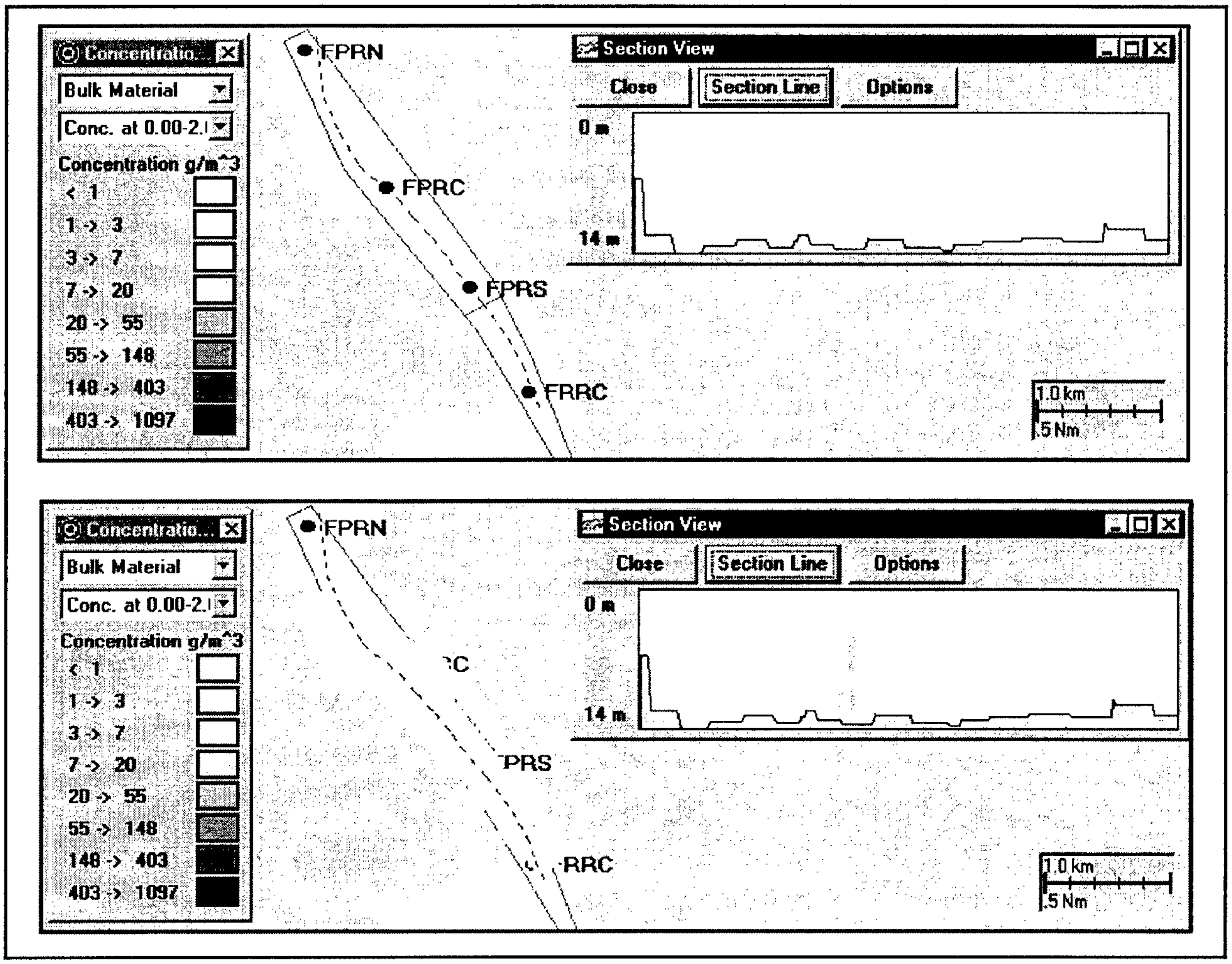

Figure 4. Extent of surface (0-2 m) sediment plume with bucket release rate of 1.5 percent for Fox Point Reach Central (FPRC) site over a typical tidal cycle. Bottom panel shows maximum down channel extent at low slack watrer and top panel shows maximum up channel extent at high slack water

The time histories of TSS concentrations at the FPRC site with a bucket release rate of 1.5 percent at various depths in the water column are shown in Figure 5. Depths are resolved into 2-m- (6-ft-) thick layers. The dredging started at hour 0 and took approximately one tidal cycle to reach a quasi steady state. The concentrations vary somewhat from one tidal cycle to the next because of the added random diffusion in the model. There is a complex structure that varies over the water column. At the surface (0-2 m (0-6 ft)), the concentration peaks every half tidal cycle in response to the TSS levels building up during the time of slack water. However, the concentrations are relatively low, e.g., less than 20 mg/L. Lower in the water column the twice-per-tidal-cycle peaks increase in magnitude, reaching 34 mg/L at a depth of 6-8 m (20-26 ft). Below this depth, maximum concentrations rise to 54 mg/L at a depth of 10-12 m (33-39 ft). The peak concentrations occur at maximum ebb when the material previously released on the flooding tide returns to the source location and adds significantly to the source-induced concentration. This does not occur during the flooding portion of the tide cycle because the greater extent of the plume during ebb (see Figure 4) does not result in material moving back over the source.

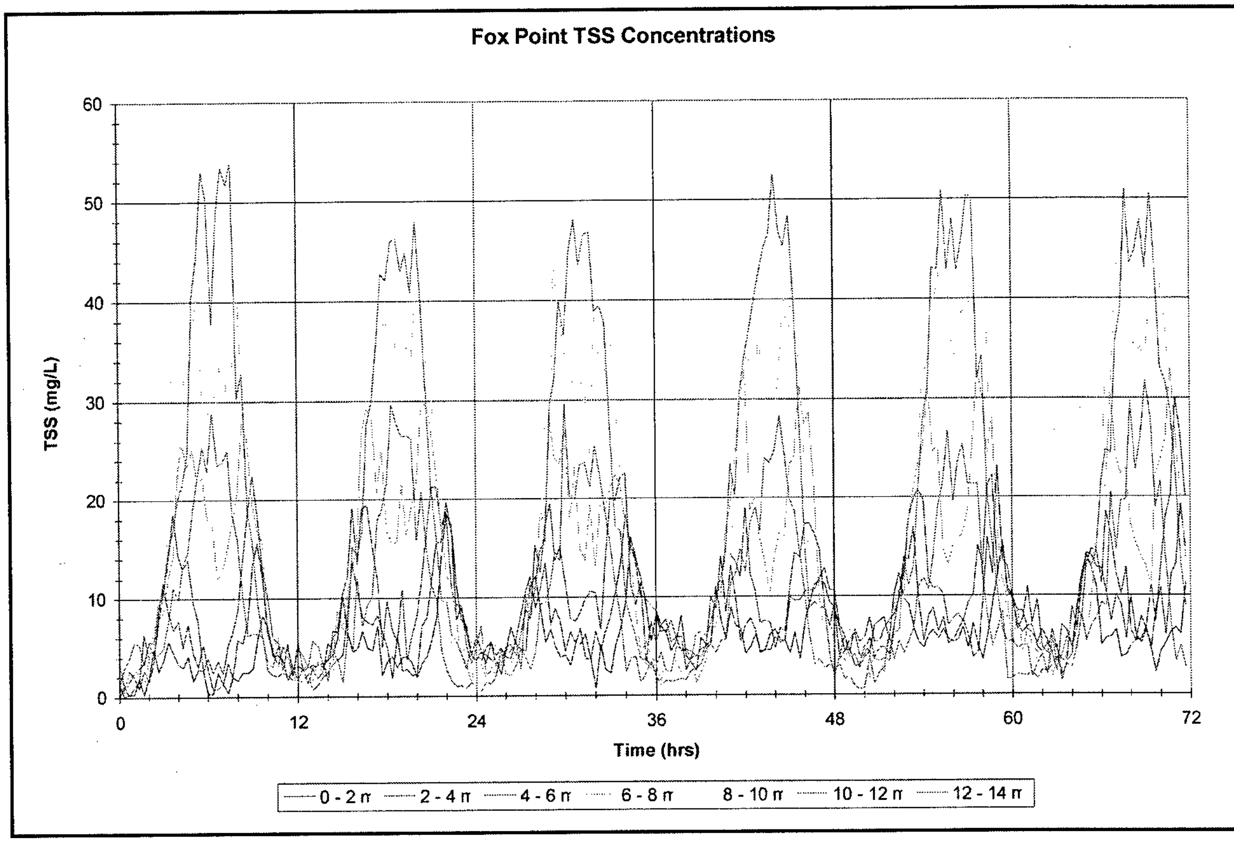

Figure 5. Time history of TSS concentrations over the water column with bucket release rate of 1.5 percent at the Fox Point Reach Central (FPRC) site. Concentrations are shown for each 2-m layer thickness from surface to bottom

The time invariant maximum extent of the plume can be displayed by showing the maximum predicted concentrations for the entire 72-hr simulation time. This extent of the plume will never actually be seen in the river because it is a composite of approximately six tidal cycles. In actuality, during ebb tide the plume will be located south of the site, while during flood the plume will be north of the site. Figure 6 shows both plan views of maximum concentrations computed during the simulation located at a depth of 10-12 m (33-39 ft) and vertical section views for a release at the FPRC site for the three release rates. It is evident that the plume extends over the entire water column, both up and down the channel from the dredging site, at some time during the simulation. The plume axis is seen to follow the channel axis since the ambient currents are aligned with the axis. The section view is defined by the dashed line in the plan view. The maximum concentration (150 mg/L at the 4 percent release rate) is seen to occur near the bottom at a depth of 10-12 m (33-39 ft). The increase in concentration as the release rate increases is approximately proportional to the rate itself, at least near the dredging site.

Figure 7 shows the time history of the water column maximum TSS concentrations at the FPRC site with a bucket release rate of 1.5 percent, along with similar concentrations at locations of 150 m (500 ft) and 300 m (1,000 ft) up and down the channel from the site. As expected, the highest concentration (peaking at 54 mg/L) occurs at the dredging site. The next highest concentration is 22 mg/L and occurs 150 m (500 ft) up channel from the site. At 300 m (1,000 ft) up channel, 150 m (500 ft) down channel, and 300 m (1,000 ft) down channel of the site, maximum concentrations range from 12 to 16 mg/L. It can be seen that the maximum concentrations drop to relatively low

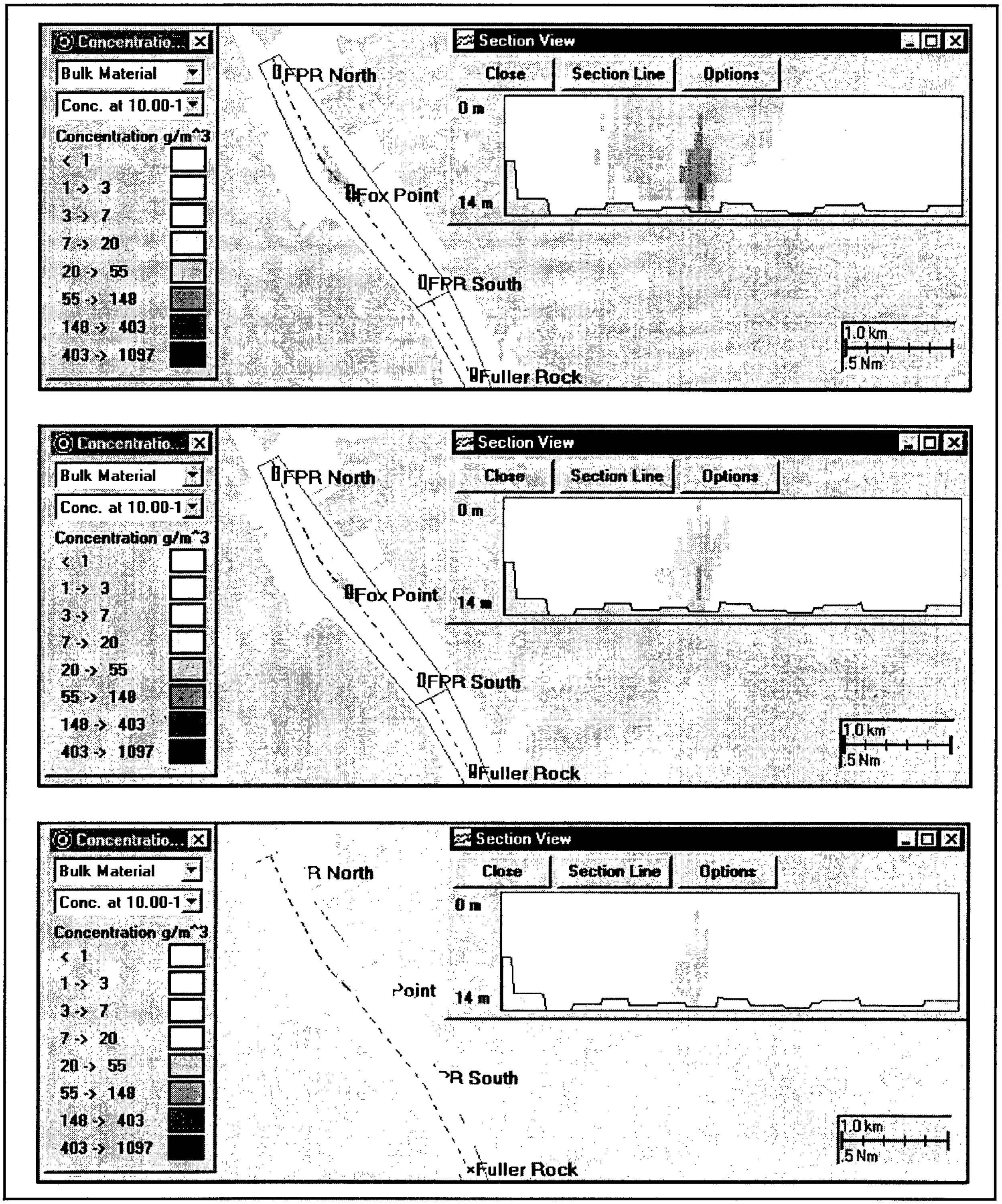

Figure 6. Maximum extent of sediment plume with bucket release rate of 1.5 percent (bottom panel), 2 percent (middle panel), and 4 percent (top panel) for Fox Point Reach Central (FPRC) site over the 3-day simulation time. Plan view shows release point, channel geometry and maximum concentrations (mg/L) at 10-12 m (33-39 ft) depth. Vertical section shows distribution of maximum concentrations (mg/L) over depth along dashed section line shown in plan view. Concentration contours correspond to ranges in the Newcombe-Jensen (1996) fisheries impact model

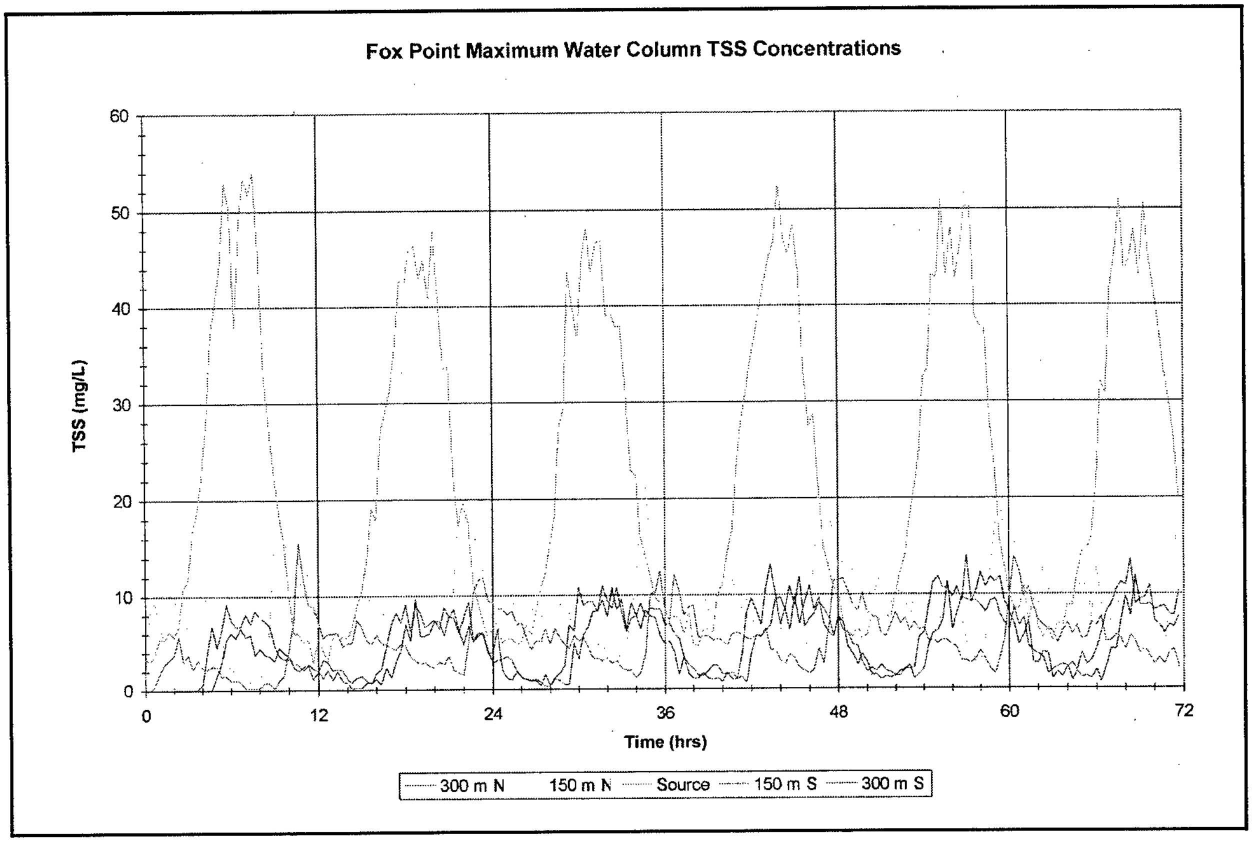

Figure 7. Time history of maximum water column TSS concentrations with bucket release rate of 1.5 percent at the Fox Point Reach Central (FPRC) site. Also shown are TSS concentrations 150 m (500 ft) and 300 m (1,000 ft) up and down channel of the site

levels as the tide changes. Table 4 summarizes the maximum peak concentrations computed and the depths where those concentrations occurred. Note that some channel depths away from the source are greater than those at the source.

Figure 8 shows the time history of the vertical locations of the maximum concentrations shown in Figure 7. Since the vertical model layer resolution is 2 m (6 ft), the locations are plotted as odd numbered depths that correspond to the center of each layer. The depth of maximum concentration at the dredging site varies from -13 m (43 ft) to -1 m (3 ft) in a cyclic pattern over the tidal cycle. The vertical oscillation of maximum concentration is less for the sites further away from the source location. Thus, at 300 m (1,000 ft) down channel of the site, the relatively small concentration oscillations (0-10 mg/L) only vary from -1 m (3 ft) to -7 m (23 ft).

Figure 9 shows the time history of the water column maximum TSS concentrations at the FPRC site with a bucket release rate of 2 percent, along with maximum concentrations at locations 150 m (500 ft) and 300 m (1,000 ft) up and down the channel from the site. The highest concentrations (peaking at 72 mg/L) occur at the dredging site. The next highest concentration is 30 mg/L and occurs 150 m (500 ft) up channel. At 300 m (1,000 ft) up channel, 150 m (500 ft) down channel, and 300 m (1,000 ft) down channel from the site, maximum concentrations range from 16 to 21 mg/L. Table 4 also lists the maximum peak concentrations and the depths where the concentrations occurred for this simulation.

Table 4
Model Predicted Suspended Sediment Concentration Summary

Dredging Site	Location	At 1.5 Percent Release Rate		At 2 Percent Release Rate		At 4 Percent Release Rate	
		Maximum Concen-tration	Depth at Maximum Concen-tration	Maximum Concen-tration	Depth at Maximum Concen-tration	Maximum Concen-tration	Depth at Maximum Concen-tration
Fox Point Reach Central (FPRC)	300 m up	16	9	21	9	39	9
	150 m up	22	9	30	9	59	9
	Source	54	11	72	11	150	11
	150 m dn	14	5	19	5	35	5
	300 m dn	12	1	16	1	30	1
Bullock Point Reach South (BPRS)	300 m up	5.3	7	7.0	7	14	7
	150 m up	13	9	17	9	35	9
	Source	20	7	27	7	53	7
	150 m dn	6.6	9	8.7	9	18	9
	300 m dn	5.7	9	7.6	9	15	9
Rumstick Neck Reach Central (RNRC)	300 m up	15	9	20	9	41	9
	150 m up	19	9	25	9	51	9
	Source	22	9	30	9	60	9
	150 m dn	13	7	18	7	35	7
	300 m dn	7.3	9	10	9	21	9

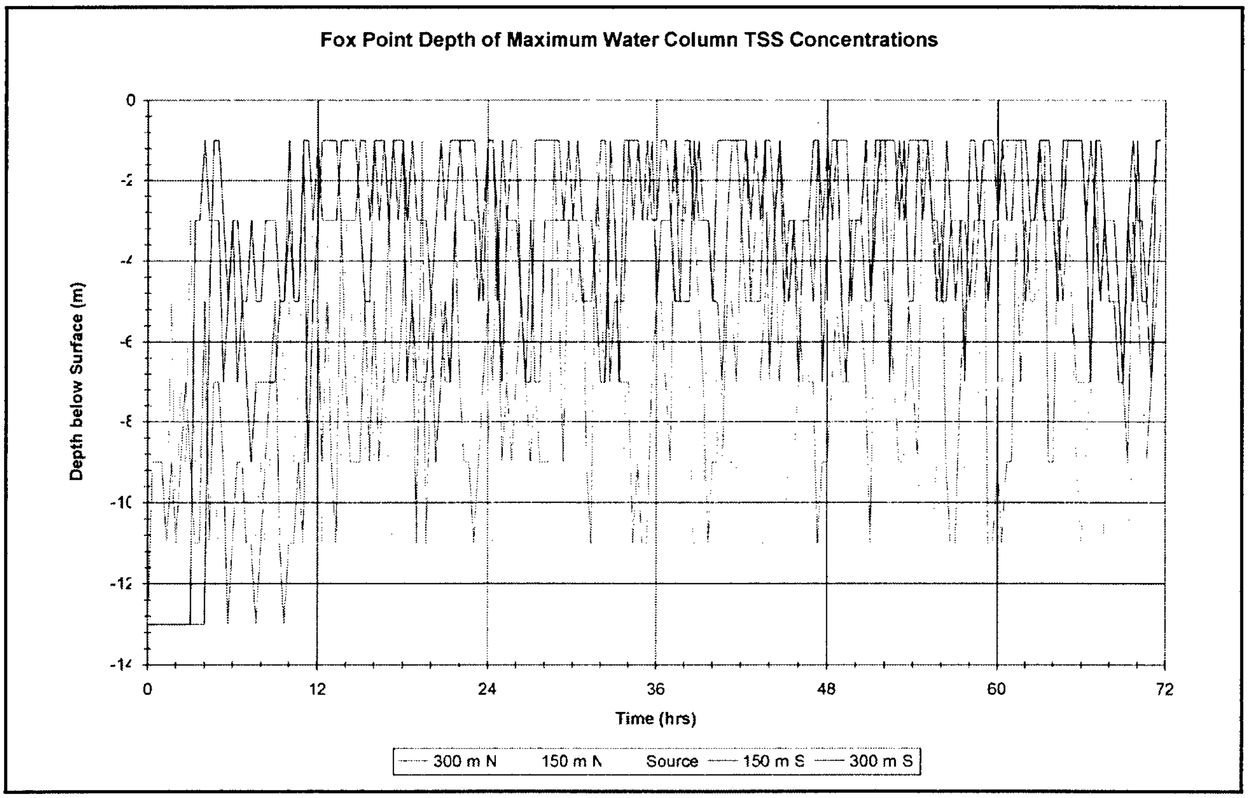

Figure 8. Time history of depth below surface of maximum water column TSS concentrations with bucket release rate of 1.5 percent at the Fox Point Reach Central (FPRC) site. Also shown are TSS concentrations 150 m (500 ft) and 300 m (1,000 ft) up and down the channel of the site

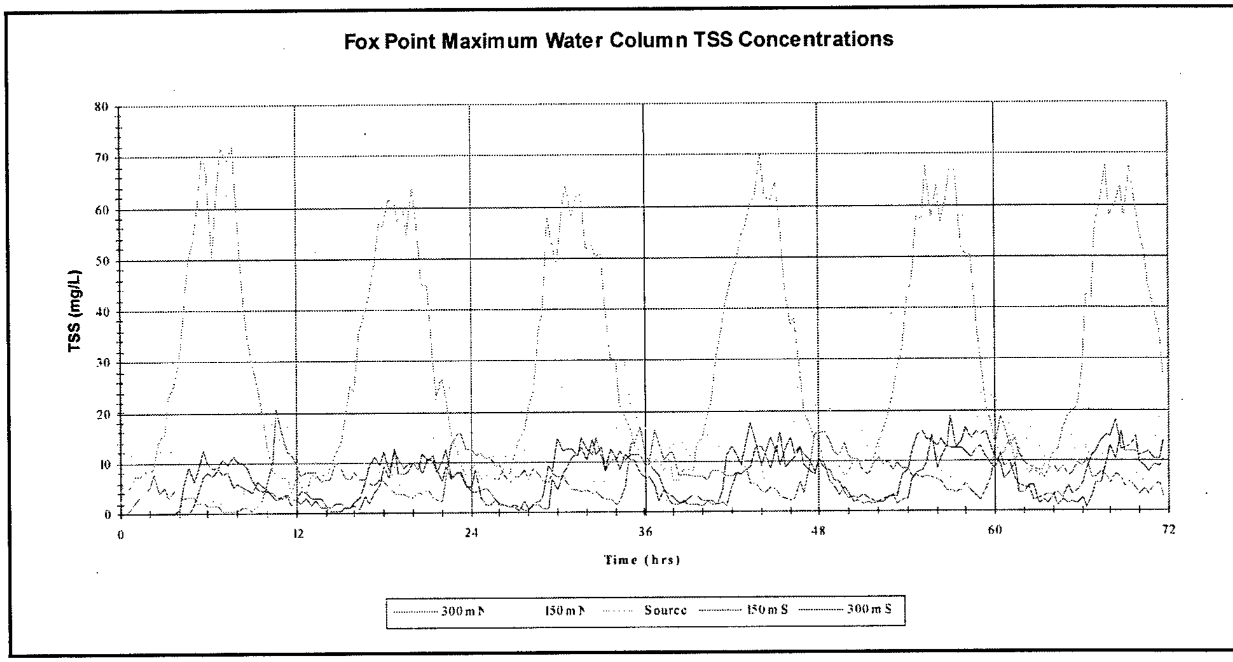

Figure 9. Time history of maximum water column TSS concentrations with bucket release rate of 2 percent at the Fox Point Reach Central (FPRC) site. Also shown are TSS concentrations of 150 m (500 ft) and 300 m (1,000 ft) up and down chane of the site

Figure 10 shows the time history of water column maximum TSS concentrations as a result of dredging at the FPRC site with a bucket release rate of 4 percent. Again, the highest concentrations (peaking at 150 mg/L) occur at the dredging site, with the next highest concentrations being 59 mg/L at 150 m (500 ft) up channel. At 300 m (1,000 ft) up channel, 150 m (500 ft) down channel, and 300 m (1,000 ft) down channel of the site, maximum concentrations range from 30 to 39 mg/L. As can be seen from an inspection of Table 4, the maximum concentrations approximately scale to the strength of the source, e.g., 54 mg/L at a 1.5 percent release rate, 72 mg/L at 2 percent and 150 mg/L at 4 percent.

Figure 11 shows plan views of maximum concentrations computed during the simulation at a depth of 6-8 m (20-26 ft) and vertical section views through the main axis of the plume at the Bullock Point Reach South (BPRS) site. As for the Fox Point Reach sites, the plume axis is seen to generally follow the channel axis. Release rates of 1.5, 2, and 4 percent are shown in the lower, center and upper panels, respectively. The maximum concentrations at the source are 20, 27, and 53 mg/L for the 1.5-, 2-, and 4-percent release rates, respectively. The section view is defined by the dashed line in the plan view. Summary concentration information for this simulation is also presented in Table 4.

Figure 12 shows plan views of maximum concentrations located at a depth of 8-10 m (26-33 ft) and vertical section views through the main axis of the plume at the Rumstick Neck Reach Central (RNRC) site. As for the other two sites, release rates of 1.5 percent, 2 percent and 4 percent are shown in the lower, center and upper panels, respectively. At this site, the plume axis is seen to be approximately 25° clockwise from the channel axis due to the direction of the currents at the site not being aligned with the channel axis. The maximum concentrations at the source are 22, 30, and 60 mg/L for the 1.5-, 2-, and 4-percent release rates, respectively.

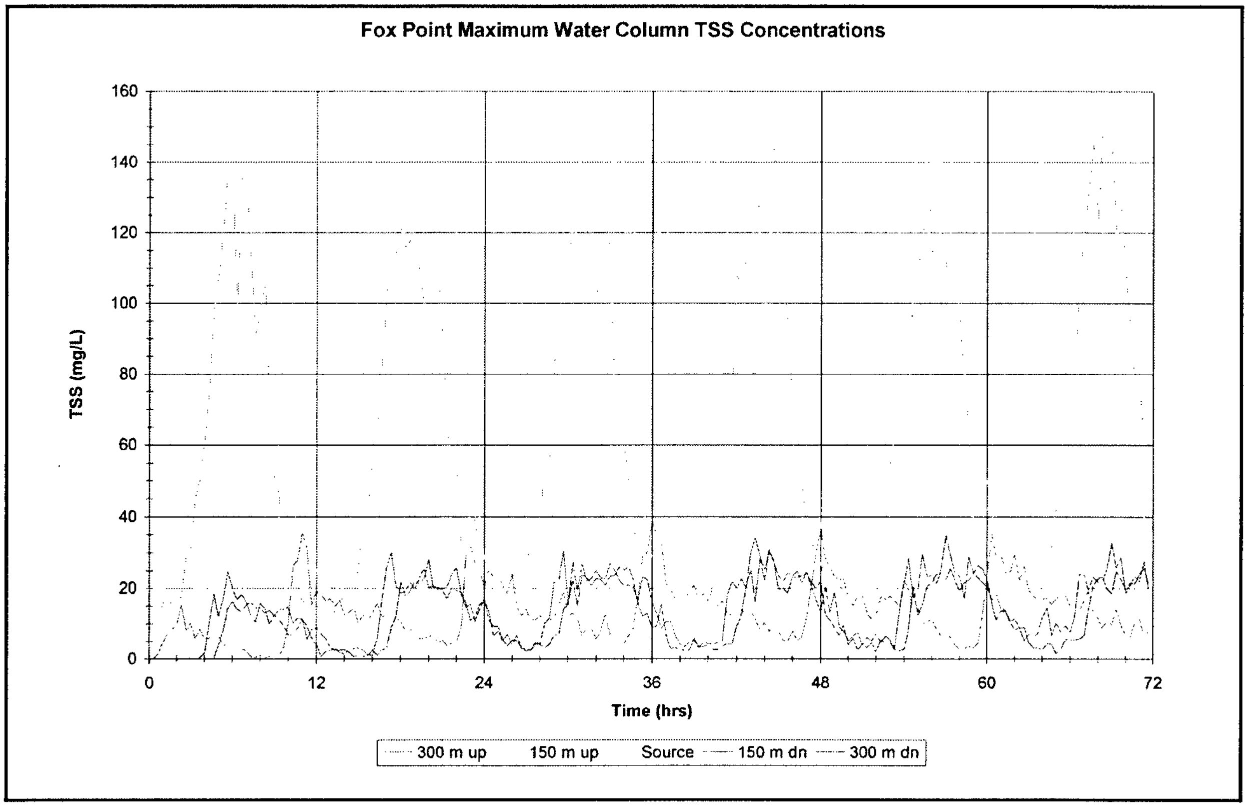

Figure 10. Time history of maximum water column TSS concentrations with bucket release rate of 4 percent at the Fox Point Reach Central (FPRC) site. Also shown are TSS concentrations of 150 m (500 ft) and 300 m (1,000 ft) up and down chane of the site

In summary, dredging in the Fox Point Reach results in the largest TSS concentrations. This is because the available water volume for dilution of the sediment plume is smallest. Results due to dredging in the Bullock Point Reach South and Rumstick Neck Reach are similar since they do not appear to be limited by available water volume for dilution.

Using a 2 percent bucket release rate, a series of plumes generated simultaneously at multiple dredging sites was also simulated. Figure 13 shows both plan views of maximum concentrations computed during the simulation at a depth of 8-10 m (26-33 ft) and vertical section views with dredging occurring at both the Fox Point North (FPRN) and Central (FPRC) locations. The maximum extent of the plumes from each site overlap into each other at concentration levels less than 7 mg/L. The up and down channel extents of the plumes are similar to the case of a single release in that the second release does not significantly influence the concentrations on the other side of the first release site. The maximum concentrations at both sites occur near the bottom at a depth of 8-10 m (26-33 ft) with concentration levels in the 55-148 mg/L range. The extent of the maximum concentration plume greater than 3 mg/L at 9 m (30 ft) is approximately 2.3 km (1.4 mi). There are only two relatively small locations with concentrations greater than 20 mg/L surrounding the release sites.

Figure 14 shows both plan views of maximum concentrations computed during the simulation located at a depth of 8-10 m (26-33 ft) and vertical section views for the case of dredging occurring simultaneously at both the Fox Point Reach Central (FPRC) and Fuller Rock Reach Central (FRRC)

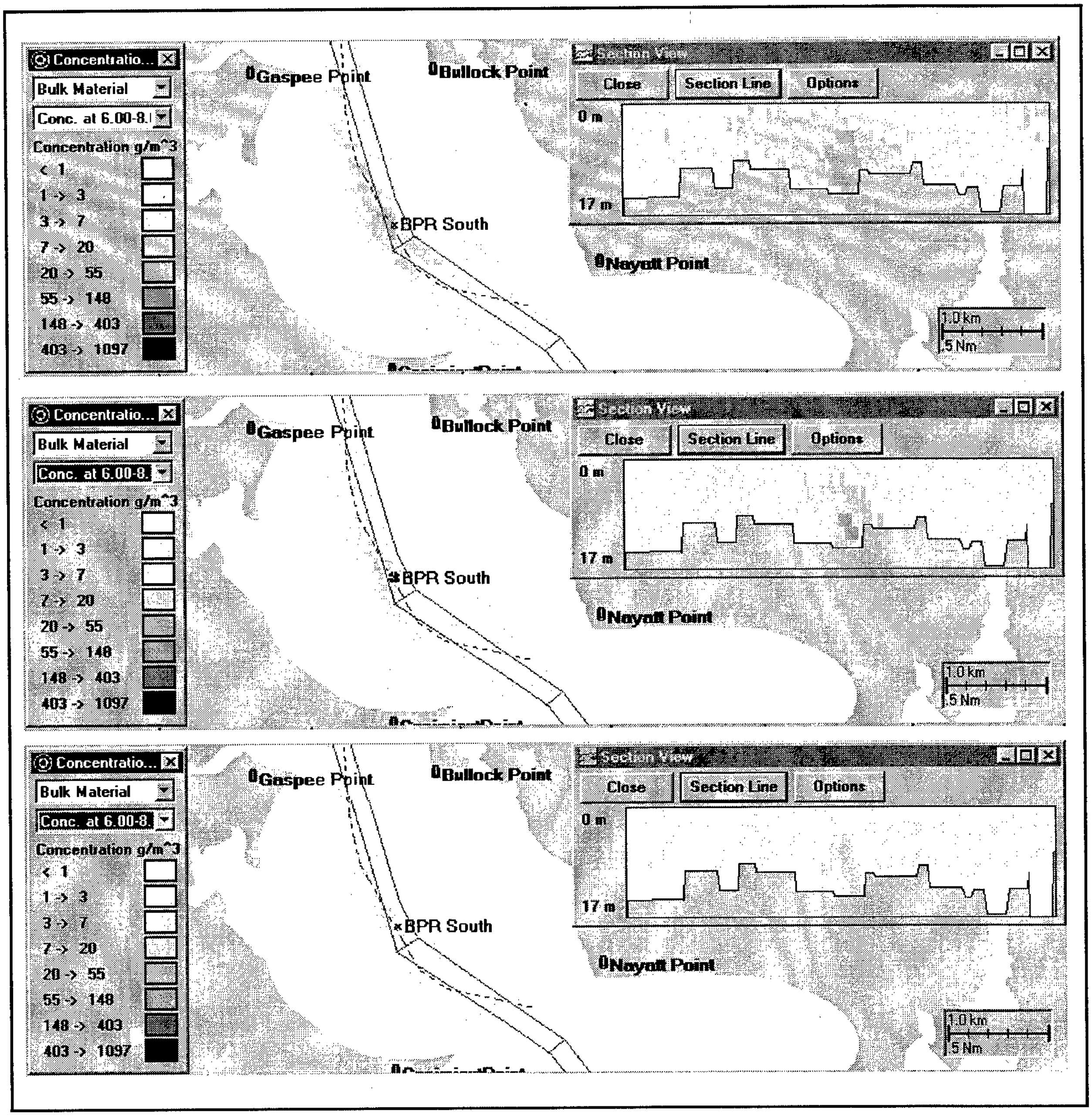

Figure 11. Maximum extent of sediment plume with bucket release rate of 1.5 percent (bottom panel), 2 percent (middle panel), and 4 percent (top panel) for Bullock Point Reach South (BPRS) site over the 3-day simulation time. Plan view shows release point, channel geometry and maximum concentrations (mg/L) at 10-12 m (33-39 ft) depth. Vertical section shows distribution of maximum concentrations (mg/L) over depth along dashed section line shown in plan view. Concentration contours correspond to ranges in the Newcombe-Jensen (1996) fisheries impact model

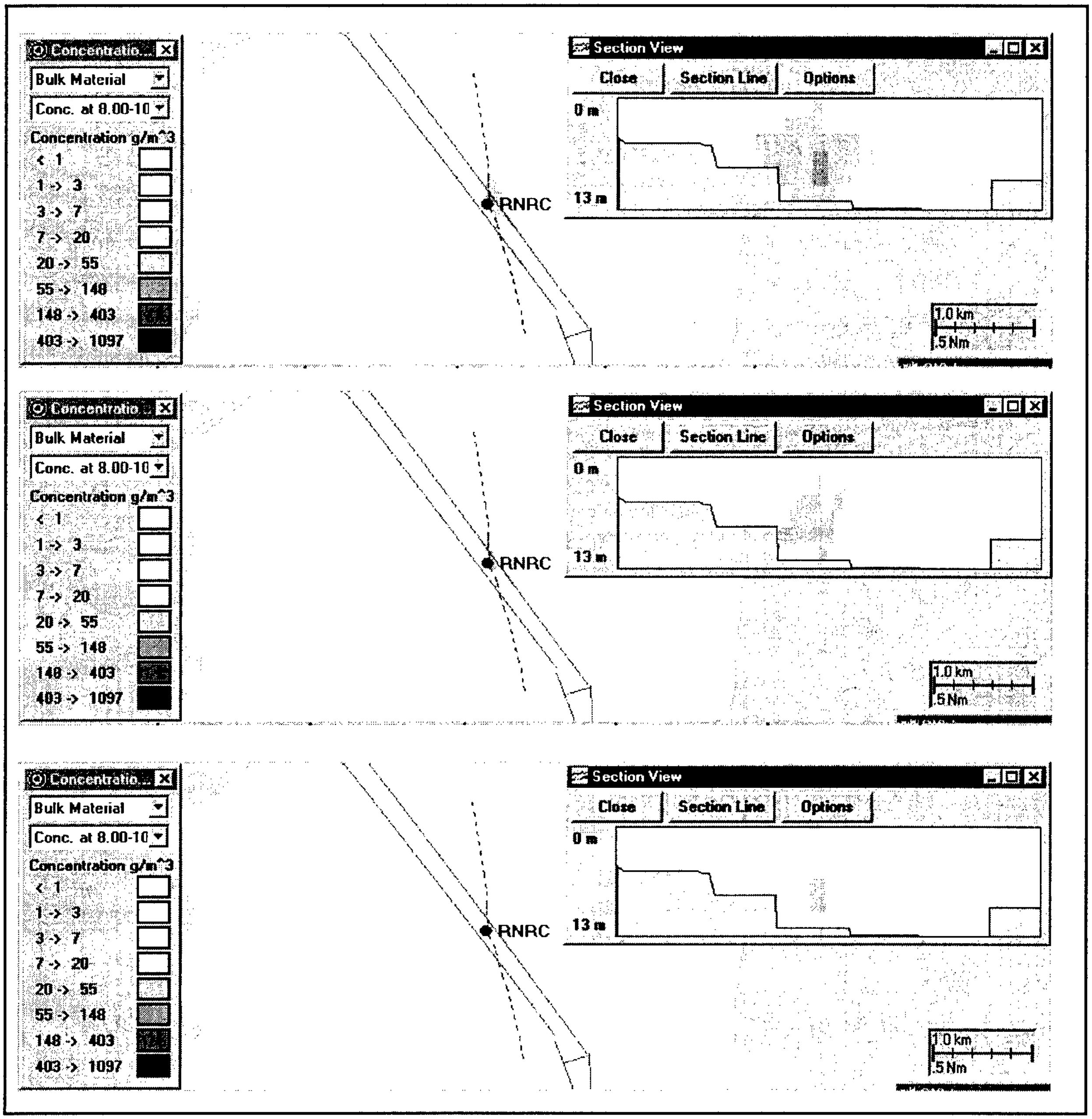

Figure 12. Maximum extent of sediment plume with bucket release rate of 1.5 percent (bottom panel), 2 percent (middle panel), and 4 percent (top panel) for Rumstick Neck Reach Central (RNRC) site over the 3-day simulation time. Plan view shows release point, channel geometry and maximum concentrations (mg/L) at 10-12 m (33-39 ft) depth. Vertical section shows distribution of maximum concentrations (mg/L) over depth along dashed section line shown in plan view. Concentration contours correspond to ranges in the Newcombe-Jensen (1996) fisheries impact model

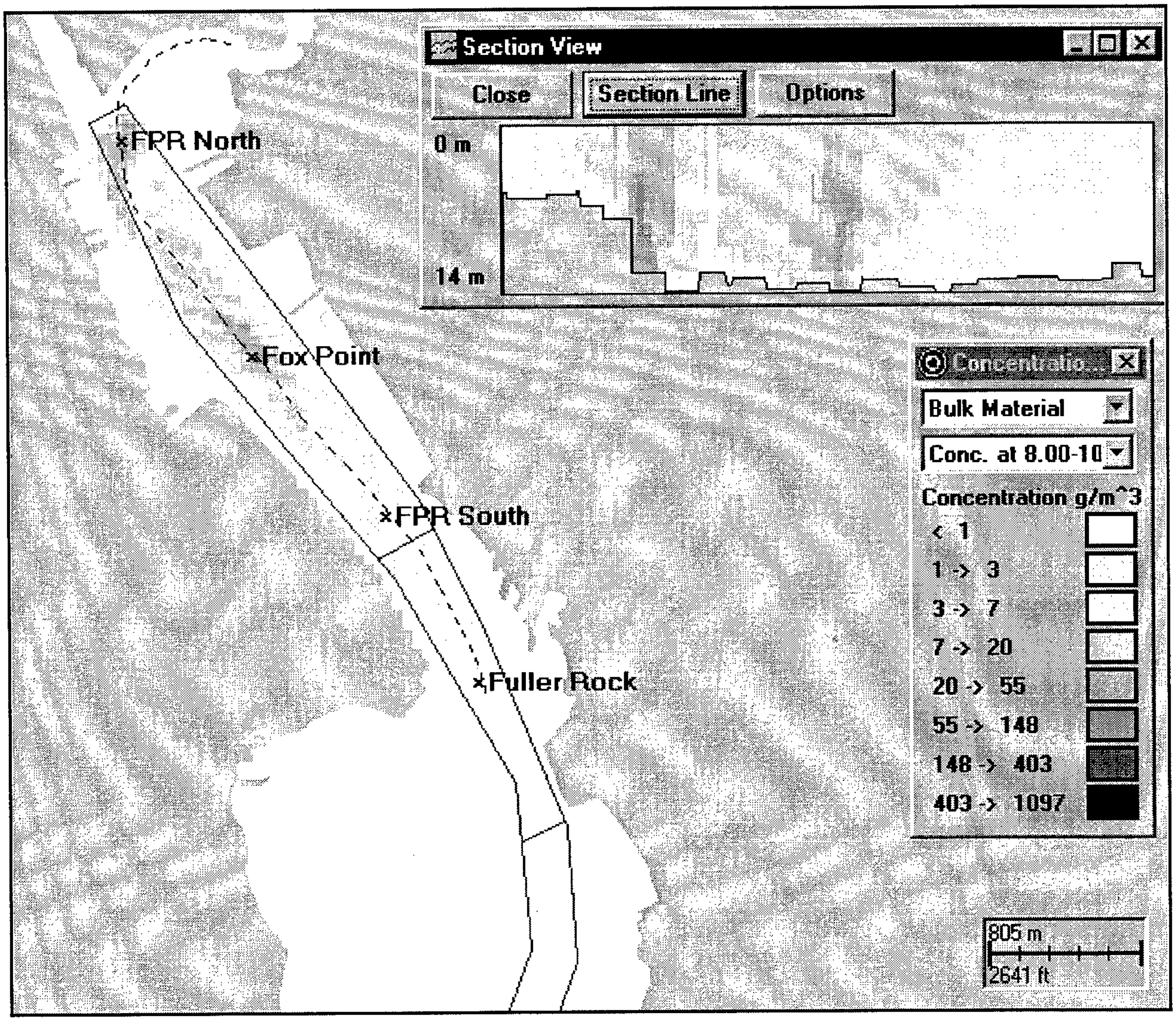

Figure 13. Maximum extent of sediment plume with bucket release rate of 2 percent for Fox Point Reach North (FPRN) and Central (FPRC) sites over the 3-day simulation time. Plan view shows release point, channel geometry and maximum concentrations (mg/L) at 8-10 m (26-33 ft) depth. Vertical section shows distribution of maximum concentrations (mg/L) over depth along dashed section line shown in plan view. Concentration contours correspond to ranges in the Newcombe-Jensen (1996) fisheries impact model

locations. Again, the maximum extent of the plumes from each site overlap into each other at concentration levels around 7 mg/L and the maximum concentrations at both sites occur near the bottom at a depth of 8-10 m (26-33 ft) with levels in the 55-148 mg/L range. However, the extent of the maximum concentration plume greater than 3 mg/L at a depth of 9 m (30 ft) is approximately 3.9 km (2.4 mi) for dredging occurring simultaneously at the FPRC and FRRC sites. There are only two relatively small locations with concentrations greater than 20 mg/L surrounding the release sites.

Results for the case of simultaneous dredging at three sites (FPRN, FPRC and FRRC) are shown in Figure 15. The results are similar to the two-release site cases (Figures 13 and 14) except that

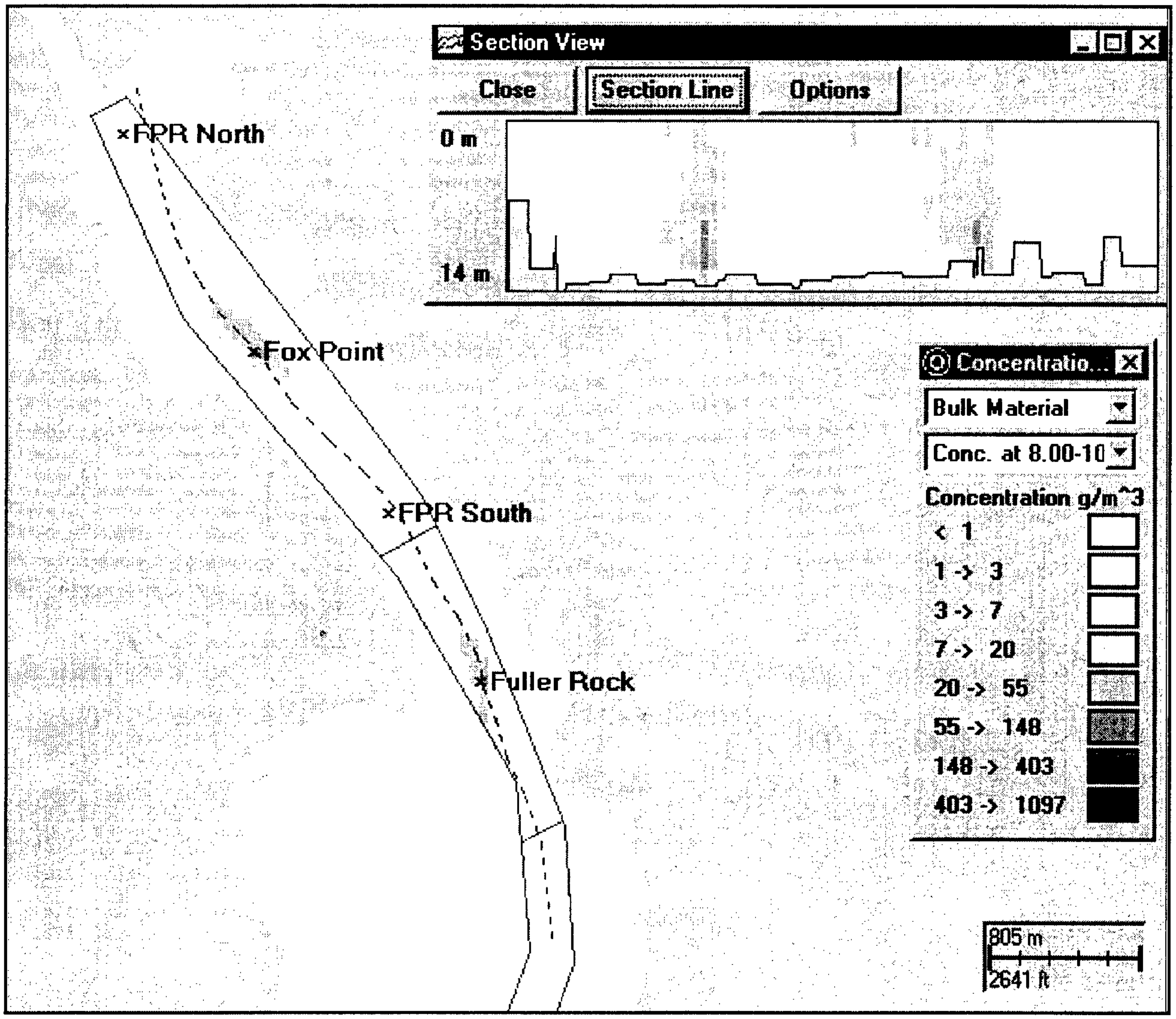

Figure 14. Maximum extent of sediment plume with bucket release rate of 2 percent for Fox Point Reach Central (FPRC) site and Fuller Rock Reach Central (FRRC) site over the 3-day simulation time. Plan view shows release point, channel geometry and maximum concentrations (mg/L) at 8-10 m (26-33 ft) depth. Vertical section shows distribution of maximum concentrations (mg/L) over depth along dashed section line shown in plan view. Concentration contours correspond to ranges in the Newcombe-Jensen (1996) fisheries impact model

the extent of the maximum concentration plume greater than 3 mg/L at 9 m (30 ft) is now approximately 4.3 km (2.6 miles). As for the case of simultaneous dredging at two sites, there are only two relatively small locations with concentrations greater than 20 mg/L surrounding the release sites.

SUMMARY AND CONCLUSIONS: A 3-D hydrodynamic model was applied to the Providence River Harbor and Channel area to generate a representative set of currents in the Providence River and Upper Narragansett Bay for input to SSFATE, which then computed the transport, dispersion, and settling of the dredged material released at selected sites.

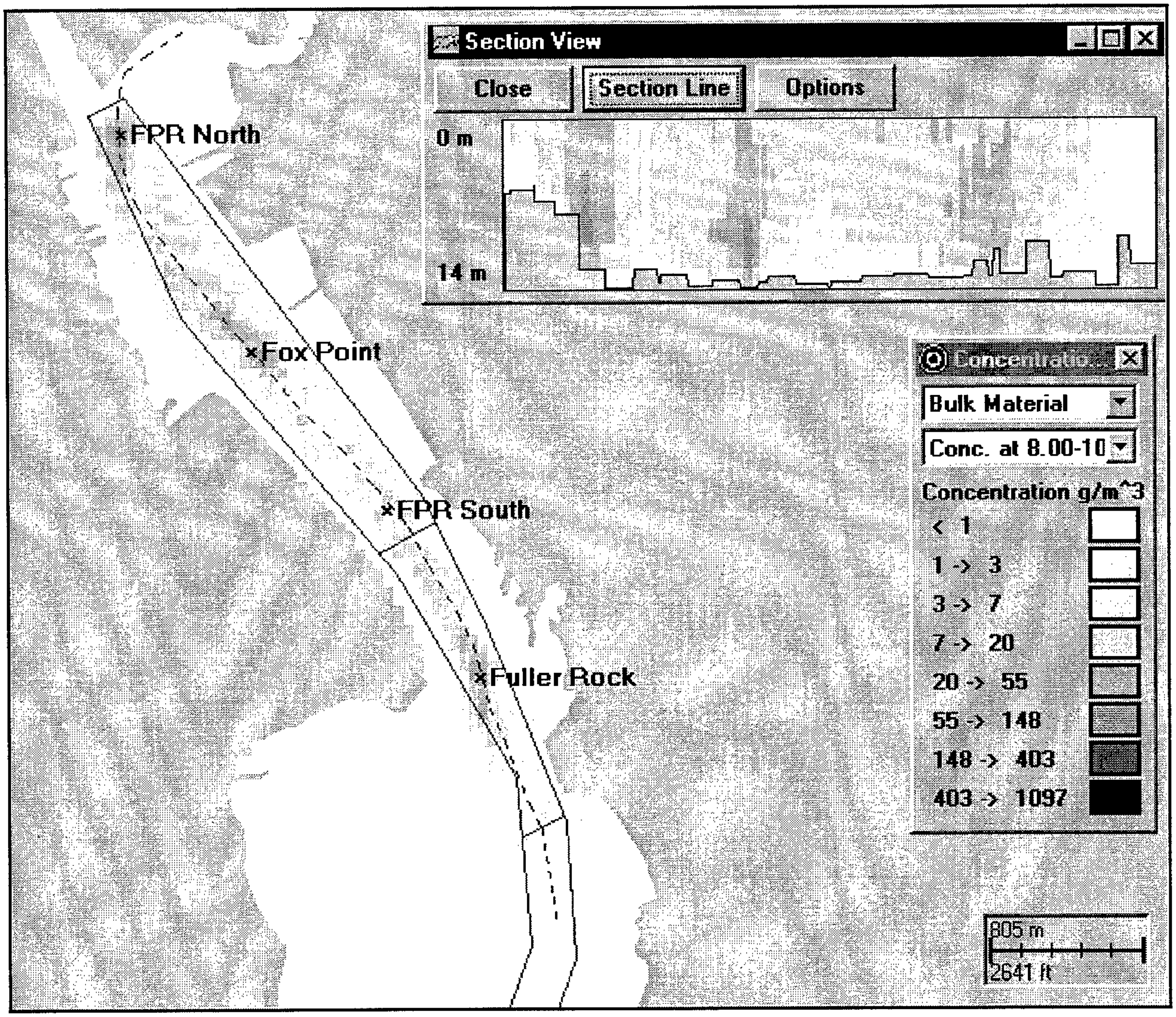

Figure 15. Maximum extent of sediment plume with bucket release rate of 2 percent for Fox Point Reach North (FPRN) and Central (FPRC) sites and Fuller Rock Reach Central (FRRC) site over the 3-day simulation time. Plan view shows release point, channel geometry and maximum concentrations (mg/L) at 8-10 m (26-33 ft) depth. Vertical section shows distribution of maximum concentrations (mg/L) over depth along dashed section line shown in plan view. Concentration contours correspond to ranges in the Newcombe-Jensen (1996) fisheries impact model

The dredging sites were selected to be representative of locations along the length of the channel from the Fox Point Reach to the Rumstick Neck Reach where dredging will occur. The model simulated the release of material over the water column individually from three separate sites and then from two and three sites simultaneously. Three release rates of 1.5, 2, and 4 percent of the total dredged material were used to simulate the effects of different types of buckets and barge filling protocols. Only a release rate of 2 percent was used in the simulation of dredging plumes created simultaneously from more than one site.

In general, the resulting TSS concentrations in the water column were highest in the Fox Point Reach and lower at the southern sites. This was due to the increased availability of diluting water at the

southern sites as the Providence River widened into the Upper Bay. Highest concentrations at the Fox Point Reach dredging site ranged from 54 mg/L to 150 mg/L, varying approximately linearly with the release rate. Concentrations dropped to below half that amount within 150 m (500 ft) upstream or downstream of the site and below one-third that amount within 300 m (1,000 ft) of the site. The relatively low concentrations in near surface waters peaked every half tidal cycle in response to TSS buildup during slack water conditions. The absolute highest peak concentrations occurred at a depth of 10-12 m (33-39 ft) during every tide, with the location of the instantaneous highest concentrations varying over the vertical throughout the tidal cycle. The ebb and flood plumes followed the axis of the dredged channel since it was aligned with the main flow direction.

The maximum concentrations at the Bullock Point Reach dredging site ranged from 20 mg/L to 53 mg/L and at the Rumstick Neck Reach site from 22 mg/L to 60 mg/L. Even though the release rates were the same, the concentration drop-off at 150 m (500 ft) and 300 m (1,000 ft) was less than at the Fox Point Reach site, indicating more effective dilution. As in the Fox Point Reach, the plume axis at the Bullock Point Reach was aligned with the channel axis. However, the plume axis was 25° clockwise of the channel axis at the Rumstick Neck Reach site since the current direction was not aligned with this channel.

Using a 2 percent release rate, a series of multiple release cases was also simulated. There is little interaction of the adjacent plumes generated by simultaneously dredging at multiple sites since the typical concentrations where the plumes overlap has dropped to approximately 7 mg/L. In general, the plume extents are shorter than the separation distance of the release sites. Thus, little increase in concentrations above ambient would be expected if multiple dredges were operating simultaneously.

Because decisions regarding the ultimate need for environmental windows rest with representatives of agencies involved in the dredging project coordination process, no attempt is made herein to interpret model results to that end. However, it is believed that application of SSFATE clearly provides a useful source of relevant information upon which to base such decisions. In addition to providing characterizations of suspended sediment plume dynamics that can be coupled with available information on responses of fish and shellfish to predicted concentration gradients, SSFATE can be used to explore numerous alternative dredging project scenarios. Ideally, such explorations may identify operational measures that pose minimal risk to biological resources, and thereby maintain maximum flexibility in dredging project schedules.

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